Evidence from detrital hornblende $^{40}Ar/^{39}Ar$ and zircon U-Pb ages for the sources of glacial deposits in the Prydz Bay region

S. R. Hemming,[1] S. A. Brachfeld,[2] G. E. Gehrels,[3] S. L. Goldstein,[1] and T. van de Flierdt[1]

[1]Department of Earth and Environmental Sciences and Lamont Doherty Earth Observatory of Columbia University, Rt. 9W, Palisades, NY 10964 USA (sidney@ldeo.columbia.edu) (steveg@ldeo.columbia.edu) (tina@ldeo.columbia.edu)
[2]Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ 07043 USA (brachfelds@mail.montclair.edu)
[3]Department of Geosciences, University of Arizona, Gould-Simpson building, 1040 E 4th St., Tucson, AZ 85721 USA (ggehrels@email.arizona.edu)

Summary We report $^{40}Ar/^{39}Ar$ analyses of individual hornblende grains and laser ablation U-Pb analyses of individual zircon grains from East Antarctic glacial diamict samples from the Prydz Bay region. Hornblende ages are strongly concentrated near 500 Ma and thus record a regional pan-African metamorphic overprint. Zircon U-Pb ages have a prominent *ca*. 550 Ma peak, also consistent with a large pan-African regional event, but additionally have an important peak in the interval between 880 and 950 Ma. In detail the cores capture sediment from different glacial flow lines based on published balance velocities, and there are some differences in the zircon U-Pb age distributions that are interpreted to reflect source variations along these different flow lines. There may also be some differences among different diamict layers from the same cores, but more work would be required to demonstrate whether this is significant.

Citation: Hemming, S. R., S. A. Brachfeld, G. E. Gehrels, S. L. Goldstein, and T. van de Flierdt (2007), Evidence from detrital hornblende $^{40}Ar/^{39}Ar$ and zircon U-Pb ages for the sources of glacial deposits in the Prydz Bay region, in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES X, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 089, 4 p.

Introduction

The Antarctic continent is largely covered by ice and thus traditional mapping of bedrock geology is limited. Diamict represents sampling and homogenization by glacial erosion and transport over large areas, providing a complement to limited and heterogeneous outcrops. In a provenance survey around Antarctica Roy et al. (accepted) found that $^{40}Ar/^{39}Ar$ ages of individual hornblende grains from marine sediment cores around Antarctica shows systematic geographic variations, where grains younger than 200 Ma dominate along West Antarctica and grains approximately 500 Ma dominate along most of the East Antarctic coast, except along the Wilkes Land sector. Sm-Nd crustal residence ages of bulk sediment from the same circum-Antarctic samples range from ~1 to 2.5 Ga. An intriguing result from the initial survey is the dominance of *ca*. 500 Ma $^{40}Ar/^{39}Ar$ ages of individual detrital hornblende grains around East Antarctica, indicative of the major tectono-thermal event on the Antarctic continent that resulted from the final amalgamation of Gondwana (e.g., Veevers, 2004; Boger and Wilson, 2005). Other major thermal events are also represented by the hornblende ages, including a minor population of Grenville ages. A substantial ancient heritage is implied by U-Pb dating of outcrops (e.g. Boger et al., 2006; Mikhalsky et al., 2006; Phillips et al., 2006) and is also highlighted by the radiogenic isotope compositions of Nd and Hf isotopes in the < 63 micron terrigenous sediment fraction (e.g., Roy et al., accepted; van de Flierdt et al., in press). In order to better understand the pre-pan-African history of the region around Prydz Bay, we have made laser ablation ICP-MS U-Pb measurements of individual zircon grains that can be compared with $^{40}Ar/^{39}Ar$ measurements of individual hornblende grains separated from glacial diamicts and Nd isotopes in the <63 micron samples collected on the Nathaniel B Palmer 2001 cruise (Fig. 1).

Samples and methods

Samples were collected from jumbo piston cores (JPC) taken in inner continental shelf basins, fjords, and bays during cruise NBP01-01 (Fig. 1). Lithic clast counts and bulk geochemistry of these samples are reported in Brachfeld et al. (this volume). JPC34 is located in the Amery shelf, directly downstream of the fast flowing Lambert glacier, and thus most likely to receive sediment from the Prince Charles Mountains. JPC40 is located off MacRobertson land and is sampling flow lines from the region underlain by the Rayner Complex (Fitzsimons, 2000). JPC25 is located in the outer part of Prydz Bay and is sampling flow lines from a separate region mapped as Rayner Complex by Phillips et al. (2006), see Fig. 1. Samples were disaggregated in deionized water and washed through a 63 micron sieve. The <63 micron fraction was saved for bulk geochemical and isotopic analysis. The > 63 micron fraction was sieved at 250 microns.

Hornblende grains were picked from the >250 micron fraction. Samples and monitor standards were co-irradiated in the Cd-lined in-core facility (CLICIT) at the Oregon State reactor. Normalization for neutron flux was based on J values calculated from analyses of the Mmhb hornblende standard with an age of 525 Ma. Single-step laser fusion $^{40}Ar/^{39}Ar$ analyses for individual grains were processed at the LDEO Ar geochronology lab using a CO_2 laser for fusion. Ages are calculated from Ar isotope ratios corrected for mass discrimination, interfering nuclear reactions, procedural blanks, and atmospheric Ar contamination.

Zircons were separated from the 63-250 micron fraction using heavy liquids and a Frantz isodynamic separator. U-Pb geochronology of zircons was conducted by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) at the Arizona LaserChron Center. The analyses involve ablation of zircon with a New Wave/Lambda Physik DUV193 Excimer laser (operating at a wavelength of 193 nm) using a spot diameter of 35 microns. Details of analysis procedures and estimates of uncertainty are provided at http://www.geo.arizona.edu/alc/detrital%20zircon%20methods.htm.

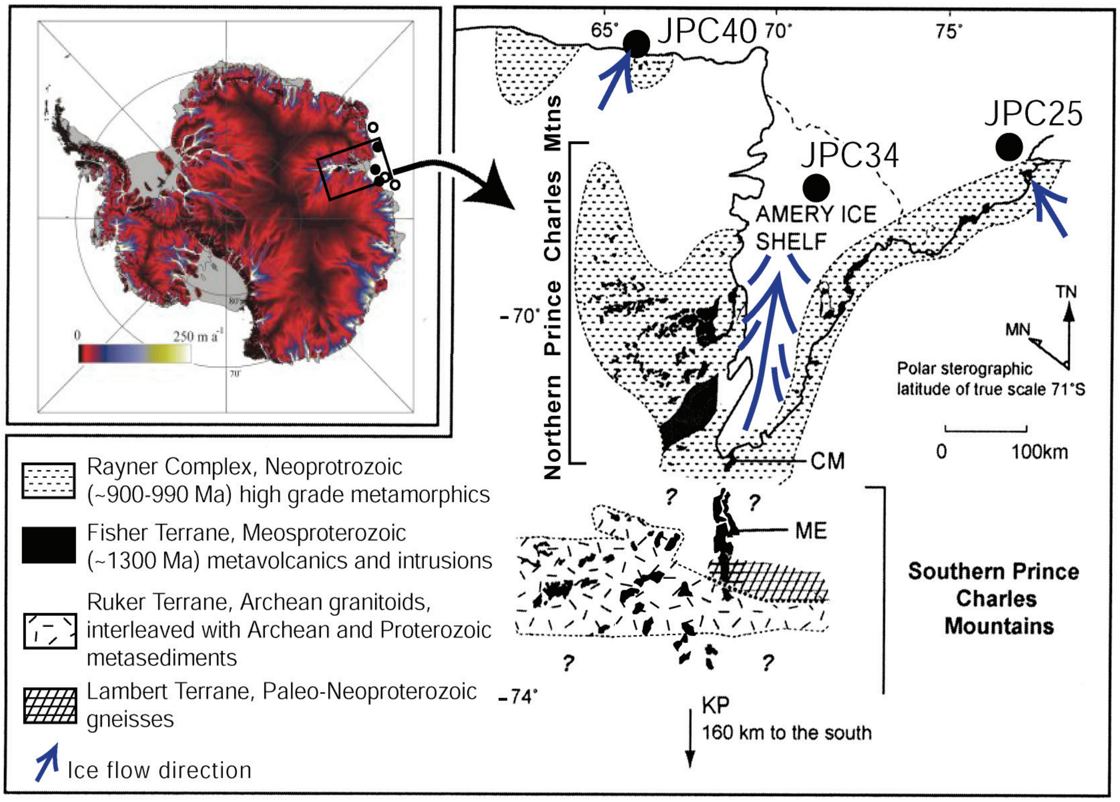

Figure 1. Geologic map (Phillips et al., 2006; based on Kamenev et al., 1993), with locations of the cores used in this study (solid circles) and in Roy et al. (submitted; shown as open circles in inset). Inset location map is taken from Bamber et al. (2000), and shows balance velocities calculated for the grounded part of the Antarctic ice sheet. Blue arrows in main map are approximate glacial flow directions based on the ice flow velocities shown in the inset map. KP is Komsomolsky Peak. ME is Mawson Escarpment.

Results

A summary of the $^{40}Ar/^{39}Ar$ hornblende and U-Pb zircon ages is presented in Figure 2. The number of hornblende grains measured for $^{40}Ar/^{39}Ar$ ages is much smaller than for the zircon U-Pb ages, but they also show a much smaller range of ages around 500 Ma (Fig. 2a). For samples from cores JPC34 and JPC25, the zircon U-Pb ages have a prominent population peak of about 540-570 Ma, with a subordinate peak at about 880-950 Ma (Fig. 2b). However, the most important peak for samples from core JPC40 is about 949 and there are limited grains with pan-African ages. The samples from JPC25 and JPC40 have very few grains older than 1.1 Ga, but there is a significant fraction of older grains in JPC34, located in the Prydz trough.

Discussion

The most obvious result of this study is the extensive pan-African ages found in both hornblende and zircon populations (Figs. 2a and 2b). The older pan-African age peak for the zircons is interpreted to be due to the lower closure temperature of hornblende, rather than a compositional bias in their provenance. Ca/K of the hornblendes is generally relatively low, so dominantly mafic sources for the hornblendes are not implied. In addition to the pan-African peak, there is a substantial Grenville population in the zircon age spectra of these diamicts. This Grenvillian peak is consistent with published compilations of U-Pb zircon ages of the region (Fitzsimons, 2000). Although there is

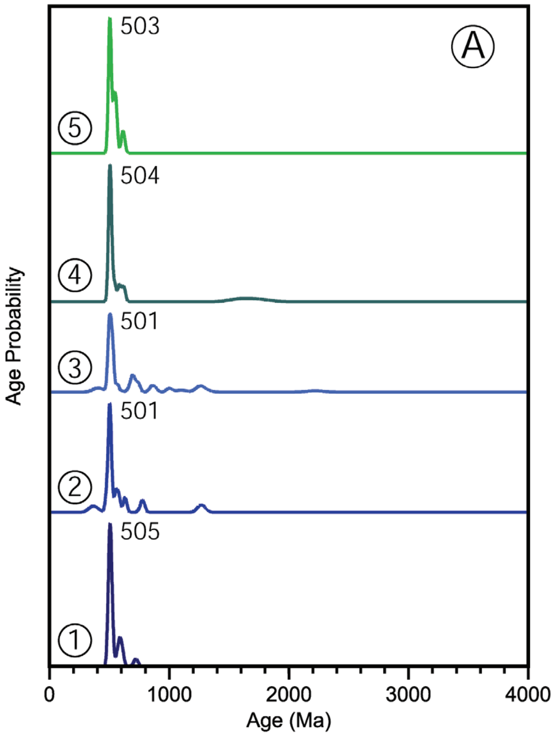

Figure 2a. Stacked probability plots of $^{40}Ar/^{39}Ar$ hornblende ages from diamicts, generated with software provided by the LaserChron facility. From bottom to top: (1) JPC3, 70-75cm (n=24), (2) JPC34 292-297 cm (n=14), (3) JPC34 345-350 cm (n=36), (4) JPC25 1305-1310 cm (n=13), (5) JPC25 1405-1410 cm (n=9). Not enough grains have been measured from JPC40 at this point.

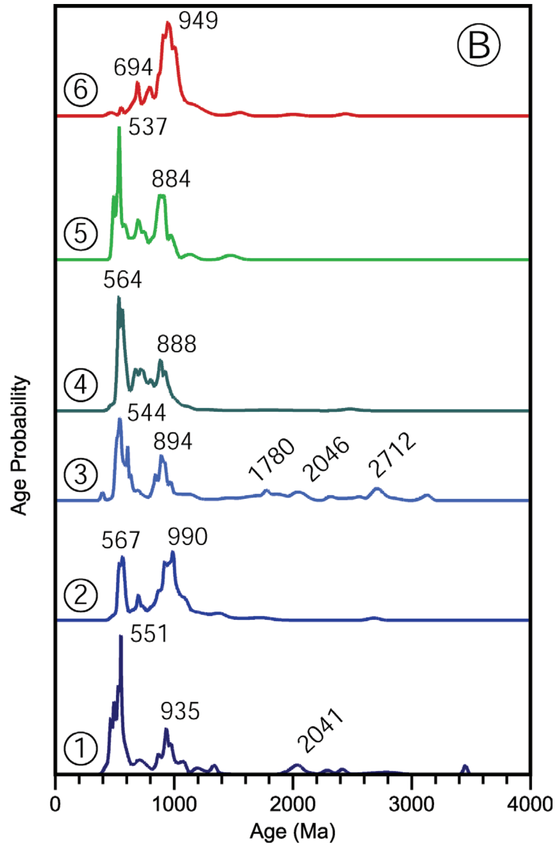

Figure 2b. Stacked probability plots of U-Pb zircon ages from diamicts. From bottom to top: (1) JPC34, 70-75cm (n=64), (2) JPC34 292-297 cm (n=78), (3) JPC34 345-350 cm (n=89), (4) JPC25 1305-1310 cm (n=92), (5) JPC25 1405-1410 cm (n=34),(6) JPC40 2370-2375 cm (n=95). Only most significant peaks are labeled in the 500-1000 Ma range. Only peaks populated by 4 or more grains are labeled in the older intervals.

a small number of nominal Grenville ages among the $^{40}Ar/^{39}Ar$ hornblende analyses, more grains would need to be measured to estimate its significance. There is a remarkable consistency in the age populations among the cores; however, in detail the cores capture sediment from different glacial flow lines based on published balance velocities (Fig. 1), and there are some differences in the zircon U-Pb age populations that are interpreted to reflect the different sources that result (Fig.2b). There may also be some differences among diamict layers from different intervals of the same cores, but more work would be required to demonstrate this is significant.

In the case of JPC34, the total number of grains older than 1.1 Ga is significant (58 of 221 acceptable analyses, where acceptable analyses have analytical uncertainties less than 10% and are less than 10% discordant), but they are distributed over a large age range. Thus more data would be necessary to make statistically significant comparisons to the Phillips et al. (2006) data from the Prince Charles Mountains. However, a visual comparison reveals overlapping populations at about 1.7-1.8 Ga (seen in their Komsomolsky Peak plot), about 2 Ga (seen in their Compston Massif, Mount Maguire and Blake Nunataks plots). A population at 2.7 in one sample overlaps a peak in their Mount Maguire plot. There does not appear to be a population that overlaps the 2.5 Ga population peak seen particularly in their Harbour Bluff, Lines Ridge and Mount Ruker plots. Specific locations named here are from the Southern Prince Charles Mountains and can be found in Phillips et al. (2006, their Fig. 3).

Summary

The work presented here is part of an ongoing effort to use the bulk sediment geochemistry and radiogenic isotopes and chronology of individual grains in order to understand the (mixed) geologic history of sediment sources from Antarctica. Antarctica is a large continent, with ice-cover that obscures a large fraction of its rich geological history. Glacial sediments are excellent archives of the geological and thermal evolution of Antarctica because they carry an integrated bedrock signature from ice-covered areas. The dominant hornblende $^{40}Ar/^{39}Ar$ age peak is ~500 Ma, and the dominant zircon U-Pb peaks are ~550 and ~900 Ma. Although many older grains are found, their ages are spread over a great range and thus more data will be needed to evaluate their significance. Glacial diamicts provide an integrated view of the regional geology that is broadly consistent with information derived from limited outcrops.

Acknowledgments. This work is funded by NSF-ANT0538580 to SRH SLG and TvdF and NSF-OPP grants 9909803 and 0348274 to SAB. Thanks to Patty Catanzaro for help with drafting figures; Liz Knapp and Malka Machlus for help with sediment processing and mineral separations; Meg Reitz, Malka Machlus, and Greg Downing for help with zircon analyses in the LaserChron facility, Malka Machlus for her help in the Ar lab; and Victor Valencia, Scott Johnston and Alex Pullen for their help during our visit to the LaserChron facility.

References

Bamber, J. L., Vaughan, D. G., and Joughin, I., 2000, Widespread complex flow in the interior of the Antarctic ice sheet, Science, 287, 1248-1250.

Boger, S. D., and Wilson, C. J. L., 2005, Early Cambrian crustal shortening and a clockwise P-T-t path from the southern Prince Charles Mountains, East Antarctica: implications for the formation of Gondwana, J. Metamorphic Geol., 23, 603-623.

Boger, S.D., Wilson, C. J. L., and Fanning, C. M., 2006, An Archaean province in the southern Prince Charles Mountains, East Antarctica: U-Pb zircon evidence for c. 3170 Ma granite plutonism and c. 2780 Ma partial melting and orogenesis, Precambrian Research, 145, 207-228.

Fitzsimons, I. C. W., 2000, Grenville-age basement provinces in East Antarctica: evidence for three separate collisional orogens, Geology, 28, 879-882.

Kamenev, E., Andronikov, A. V., Mikhalsky, E. V., Krasnikov, N. N., and Stuwe, K., 1993, Soviet geological maps of Prince Charles Mountains, East Antarctic shield, Australian Journal of Earth Sciences, 40, 501-517.

Mikhalsky, E. V., Beliatsky, B. V., Sheraton, J. W., and Roland, N. W., 2006, Two distinct Precambrian terranes in the Southern Prince Charles Mountains, East Antarctica: SHRIMP dating and geochemical constraints, Gondwana Research, 9, 291-309.

Phillips, G., Wilson, D. J. L., Campbell, I. H, and Allen, C. M., 2006, U-Th-Pb detrital zircon geochronology from the southern Prince Charles Mountains, East Antarctica- defining the Archaean to Neoproterozoic Ruker Province, Precambrian Research, 148, 292-306.

Roy, M., van de Flierdt, T. Hemming, S. R., and Goldstein, S. L.,accepted, $^{40}Ar/^{39}Ar$ ages of hornblende grains and bulk Sm/Nd isotopes of circum-Antarctic glacio-marine sediments: Implications for sediment provenance in the Southern Ocean, Chemical Geology.

van de Flierdt, T., Goldstein, S. L., Hemming, S. R., Roy, M., Frank, M. and Halliday, A. N., in press, Global neodymium-hafnium systematics-revisited, Earth and Planetary Science Letters.

Veevers, J. J., 2004, Gondwanaland from 650-500 Ma assembly through 320 Ma merger in Pangea to 185-100 Ma breakup: supercontinental tectonics via stratigraphy and radiometric dating, Earth-Science Reviews, 68, 1-132.